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TOOLS FOR INCLUDING REALISTIC REPRESENTATIONS OF OPERATOR PERFORMANCE IN DOD CONSTRUCTIVE SIMULATIONS

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Abstract

Military weapon systems are normally built to satisfy a set of requirements levied by the warfighter. All these weapon systems are manned in some sense, yet tools for quantifying the effectiveness with which a crewstation must support operator performance are lacking. Analysts and decision-makers need a means to readily model and understand the effects of human performance on total weapon system effectiveness when translating operational requirements into system requirements. This paper discusses the research and demonstration activities being conducted by the Combat Automation Requirements Testbed (CART) Program within the Air Force Research Laboratory / Human Effectiveness Directorate. CART will demonstrate how human-in-the-loop and constructive operator models and data can be integrated with Simulation-Based Acquisition activities for the purpose of defining crewstation requirements. Utilizing the Army's IMPRINT human-performance modeling environment, CART will provide High Level Architecture (HLA) interfaces that enable human-performance models to interact with constructive models of systems. A second extension will incorporate the ability to represent the goal-oriented nature of human performance. Modelers and analysts will be able to define operator goal states and priorities that dynamically drive task network models based on changing states and events in simulated military environments.

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Acronyms

CART	Combat Automation Requirements Testbed
DOD	Department of Defense
DMSO	Defense Modeling and Simulation Organization
FOM	Federation Object Model
HIP	Human Information Processor
HLA	High Level Architecture
IMPRINT	Improved Performance Research Integration Tool
MOE	Measure of Effectiveness
MOP	Measure of Performance
M&S	Modeling and Simulation
ORD	Operational Requirements Document
RCM	Requirements Correlation Matrix
RTI	Run Time Infrastructure
SAM	Surface-to-Air Missile
SBA	Simulation-Based Acquisition
SWEG	Simulated Warfare Environment Generator

Introduction

Deriving system requirements from constructive simulations

Analysts and decision-makers rely heavily on constructive simulations of a system in its intended environment to help translate mission requirements identified by the warfighter into system performance requirements. Within the constructive system simulation, levels of performance on key subsystem attributes are selectively varied and impacts on mission performance are measured. Levels of subsystem attribute performance that yield desired levels of mission performance are identified. These subsystem-attribute performance levels provide the basis for statements of system requirements. A major benefit arising from the use of objective, quantitative requirements is that they provide explicit criteria against which subsystem designs and implementations can be tested. Given that this criterion performance is achieved, there is greater assurance that desired mission performance will be obtained.

The Problem: Current constructive testbeds simulate the operator poorly

While the current state-of-the-art for constructive simulation enables development of most *system* requirements, it does not support development of *crewstation* requirements. Current constructive modeling environments, such as SWEG and BRAWLER, are limited in terms of the range and type of operator activities that can be represented and manipulated. SUPRESSOR, for example, has a 'thinker' component that permits the user to define some decision logic that leads a model to behave differently under different conditions. It does not, however, provide for detailed representation of operator behavior such as sensing information, manipulating controls, or implementing workload mitigation strategies. Another limitation of current models is the extent to which execution under specific conditions can be traced and understood. As an illustration, BRAWLER is a very detailed model in terms of representing what a fighter pilot might do in air-to-air combat. On a given run of BRAWLER, however, it is difficult to trace the execution of model components and understand *why* the components executed as they did. Finally -- hand in hand with the limitations described above -- is the difficulty in obtaining data needed to evaluate performance of such models at a detailed level.

Due to the limitations in effectively modeling the operator, the crewstation has not been considered during the constructive, simulation-based trade studies conducted early in system acquisition. Thus, the crewstation has been omitted from the trade-off process that produces requirements for many other critical subsystems. The result has been that crewstation requirements are developed relatively late in the acquisition process. Crewstation requirements that are eventually developed tend to describe components of the crewstation (e.g., displays of a certain size and resolution and specific types of controls to be used) rather than levels of operator performance that must be supported. In the absence of objective, performance-based requirements levied on the crewstation, it is more likely that crewstations will be produced with flaws that result in substandard mission performance and require remedial action during the production phase.

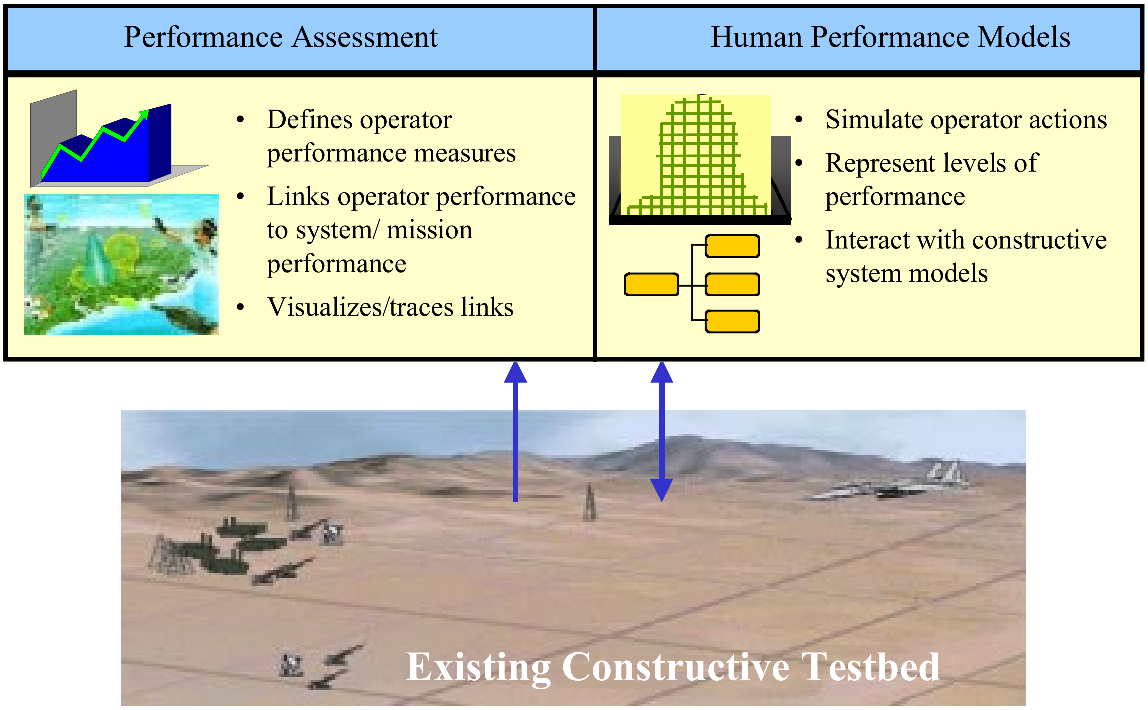

Figure 1. CART Tools for generating crewstation requirements.

System-level performance requirements need to *realistically* consider the effects of operator performance during each step of the acquisition process -- from analysis of alternatives through full-scale production. For example, a military analyst currently associated with a strike-fighter program noted that, "Every single analysis that I have ever seen has suffered from the lack of capturing smart tactics. Mistakes such as pursuing an attack when the tactic should have been 'run away' lead to mission outcomes (aircraft loss) that seem to indicate system deficiencies when in fact the system was misused tactically." Analysts and decision-makers need a means to readily model and understand the effects of human performance on total weapon system effectiveness when translating operational requirements into system requirements, and need to be able to visualize these effects at different levels of aggregation.[1] The technical objectives of the Air Force Research Laboratory's CART Program address these needs.

CART Overview

CART Objectives

The CART program will extend current constructive modeling and simulation (M&S) testbeds by providing new tools for generating crewstation requirements as illustrated in Figure 1. One is a *human performance modeling capability*. With this tool, analysts will be able to create models that simulate activities operators would perform in a system. Analysts also will be able to parameterize the models to reflect different levels of operator capability. These human performance models will be integrated with constructive models of a system and interact with the system in the context of a simulated mission. The second tool provides *performance assessment capabilities*. This tool supports generation of measures of operator performance. Operator measures will be linked to measures of system performance and mission

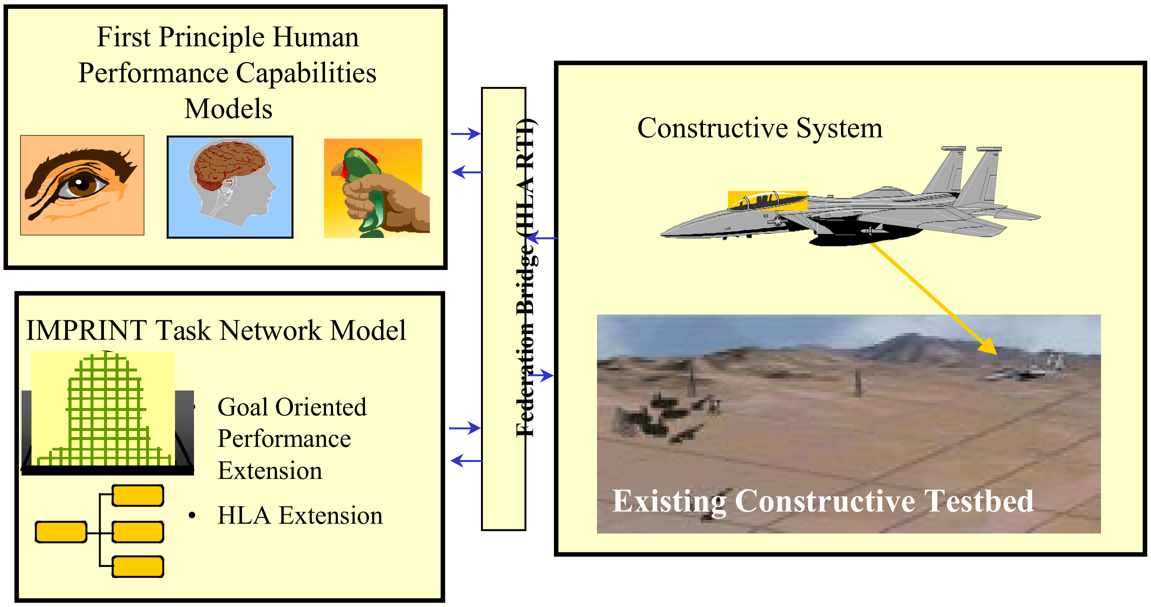

Figure 2. CART's Human Performance Modeling Architecture.

effectiveness. With this tool, relationships between operator performance and system and mission performance can be visualized and traced. Levels of operator performance (MOPs) that are required to produce desired mission outcomes (MOEs) can be identified.

CART human performance modeling architecture

The architecture being used for integrating human performance models into constructive level simulations is shown in Figure 2. The human performance-modeling environment will be a hybrid of two approaches to human performance modeling: *task network modeling* and *first principle modeling*. Task network modeling will be the core human-performance modeling method. Task network modeling breaks the human performances of interest into a series of tasks characterized in terms of performance times, accuracy, and probabilities. Tasks are linked together into networks that represent sequences and paths performance can take. Within CART, the IMPRINT tool mentioned earlier will be used to provide baseline task network modeling capabilities. IMPRINT will be extended to provide representation of the goal-oriented nature of human performance and to communicate with external models via the HLA. While task network models provide an easy-to-understand representation of human performance, their fidelity is limited in terms of modeling specific human capabilities such as cognition and perception. For this reason, users will have the ability to augment the task network models with first-principle models that provide high-fidelity representations of human capabilities. Essentially, tasks in the task network will call first-principle models that represent the capabilities required in the task. The first-principle model will execute the capability and return the parameters required by the task network model.

The DMSO's HLA will provide the communications link between models. Data will be passed between architecture components using the HLA RTI. The task network model will receive data regarding system and mission status from the constructive system simulation and data about the external world (e.g., SAM launches) from the mission environment models. Actions to be implemented by the system (e.g., maneuver, target designation, weapon launch) will be passed to the constructive simulation by the task network model.

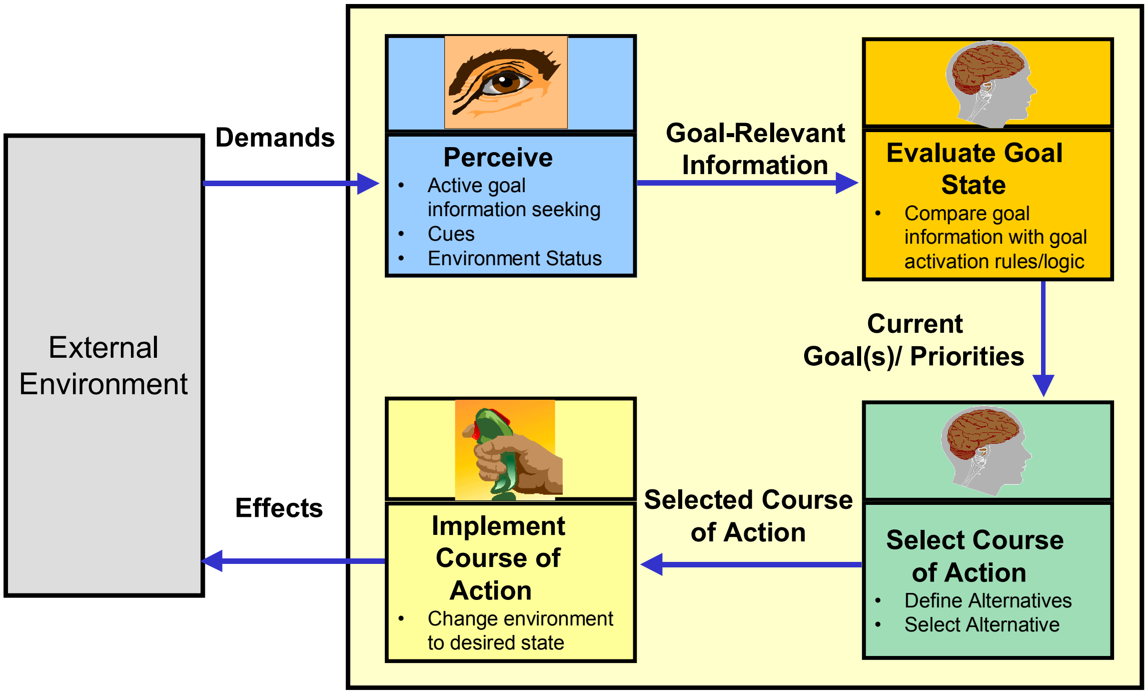

Figure 3. Basic Human Information Processor Model (after Hendy and Farrell, 1997)[2]

Similarly, the task network model will use the RTI to pass data to first principle models to initiate them and receive the results of first-principle model execution.

Modeling Theory and Methods

Underlying assumptions and theory

CART's approach to human performance modeling is based on two fundamental assumptions. The first is that operator success is achieved by meeting mission performance demands that are levied by factors external to the operator. This is consistent with our view of the operator as a constrained component of the system. The demands are, in effect, constraints. If the operator does not perform within the constraints (meet demands) mission performance can be degraded. The second assumption is that, in meeting demands, the operator functions as an information-processor.[2] That is, the operator identifies current demands and selects and implements courses of action to meet those demands. In this process the operator seeks information from the environment about demands and applies information held internally and additional information from the environment to meet those demands as illustrated in Figure 3. Inherent in the information processor are capabilities and limitations that interact with demands and that can affect mission outcomes.

In order to successfully meet mission demands, the operator must determine which demands are impinging at a point in time, prioritize them if there are multiple demands, and then act to meet those demands. Demands from the environment are first perceived by the operator using one of the five senses. Perception of demands is an active process in which the operator purposefully seeks specific information about current demands. This information seeking is focused and methodical, based on training and experience. Given that multiple demands can be active at the same time, a mechanism is needed to sort among concurrent demands to chose which one(s) get serviced first. The model assumes that in a given system-mission environment the operator has an internal goal structure that helps him assess and prioritize demands to be met. These goals are associated with functions that must be

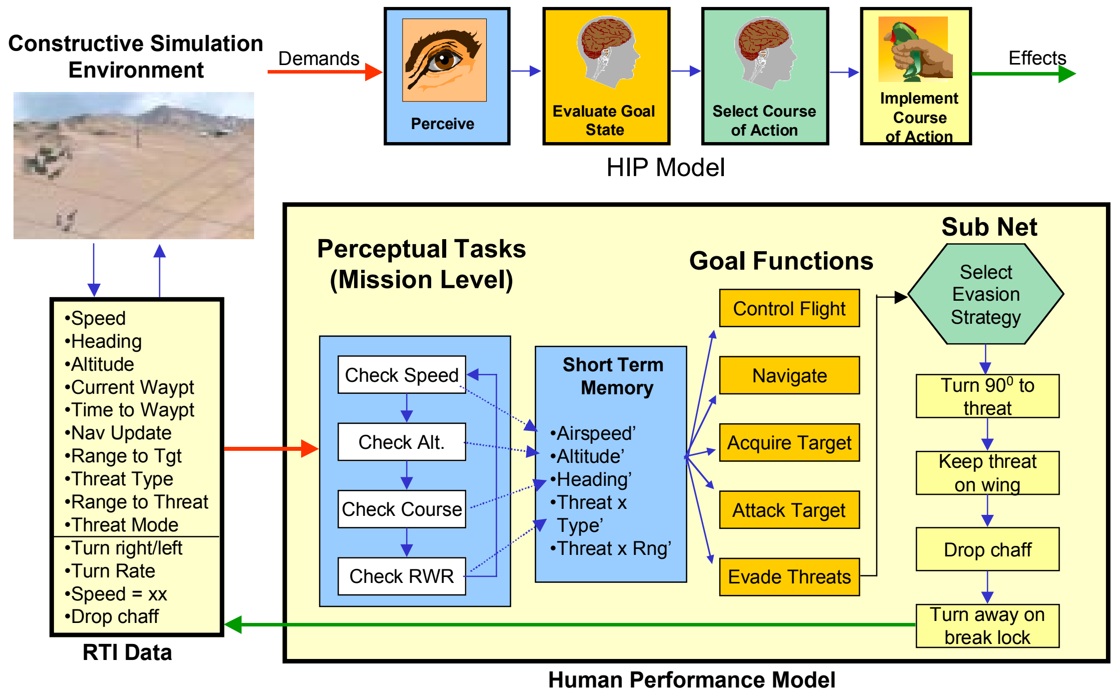

Figure 4. Representing the Human Information Processor (HIP) with IMPRINT.

performed successfully to accomplish the mission. The goals are defined in terms of states of the external environment that the operator seeks to control. In goal-state evaluation, information from the environment provided by perceptual processes is compared with internally held knowledge of expectations about world states and rules for determining when a goal state becomes active. When goals become active, attention turns to selecting a course of action for bringing the current state of the world into the desired state. Course-of-action selection can involve a variety of levels of cognitive processing (e.g., skill-based, rule-based, or knowledge-based reasoning). It can also involve other perception and action components that are applied to gain additional information needed to select a course of action. Once a course of action is selected, it is implemented and its effect on the environment is observed. Course-of-action implementation generally involves motor activity (e.g., manipulate a control or throw a switch). Observation-of-effect is performed by the perceptual capabilities, which, in turn, feed the goal states and the cycle repeats itself until the desired state is achieved.

Readers familiar with control theory will recognize that the information processor model is really a type of a closed-loop control model.

<u>Representing the human information processor (HIP) model with IMPRINT</u>

The model implementation is shown schematically in the lower half of Figure 4, and corresponds to the HIP model that is shown above it in the figure.

The constructive simulation environment (i.e., the models of the system and mission environment entities) will provide the representation of demands to the information processor. Passage of data between the human performance model and the constructive testbed will be controlled by the HLA runtime infrastructure (RTI). IMPRINT collects 'demands' data from the RTI and stores it in user-defined variables.

Information seeking about current demands in the mission environment will be performed by a network of tasks representing perceptual tasks. The network will control the sequence and timing according to which the operator 'observes' displays and instruments and 'listens'

for communications, tones, alarms, etc. Perceptual information seeking is driven by information needs for evaluating goals. Perceptual tasks will update other user-defined variables that represent short-term memory. This reflects the fact that perception is a constrained process -- we cannot know everything about our world instantaneously. What we know is determined by when it is perceived -- which is, in turn, controlled by our 'schedule' of perceptual activity.

Goal states are evaluated from the contents of short-term memory. Thus, conditions in the environment can change such that a goal should become active, but the goal will not actually trigger until that new condition is perceived and reflected in short term memory. Goals evaluate on every cycle of the model. Initiating-condition expressions provided by the user determine when a goal triggers. Once initiating conditions have been met, additional logic provided by the user in regard to goal priority and activation relative to other higher-priority goals determines whether the goal actually becomes active. The goal state 'evade threats', for example, would be triggered when threats were present and within a certain proximity to the aircraft. Because threat evasion is such a high priority goal, the model developer might decide to suspend activity under any other goal state that might be triggered while the evasion goal state is active.

Task sub-networks are activated for goals that become active. Within these sub-networks, decision nodes can be provided that represent alternative courses of action. Within the decision node, logic can be specified that selects the course of action best suited for the current circumstances. When decision-making is complex, course-of-action selection itself might be represented by a network of tasks. Under the threat-evasion example, selecting a course of action would probably involve considering the type of threat and choosing from among a set of evasion options (e.g., maneuver, countermeasures, or a mix of both).

As the course of action executes, inputs to the constructive system are provided via updates to user defined variables that, in turn, update variables in the RTI. The constructive system model receives this data from the RTI and then changes its performance accordingly. Continuing with the threat evasion example, a course-of-action implementation strategy might be applied that involves maneuvering the aircraft while applying some countermeasures. As the task network model executes these actions, data are sent across the RTI to command the constructive system models to implement the corresponding actions.

CART Implementation in the Acquisition Process

What CART adds to the acquisition process

CART is being developed to support the system acquisition process by enhancing the constructive simulation activities used to explore system concepts and develop requirements. Once the needs of a given acquisition program are thoroughly understood, the CART process for achieving human-performance-model integration involves:

- decomposing a system's mission to understand the various human and system tasks,
- developing human performance models that characterize human behavior on the tasks and that will interface with the existing constructive environments,
- collecting and analyzing the data to identify levels of task performance that determine mission success,
- translating the findings into crewstation requirements that state the levels-of-performance that the crewstation must enable.

The end result of CART implementation in the acquisition process is the development of *crewstation performance requirements* that will supplement the higher-level system capability requirements.

Role of the Requirements Correlation Matrix (RCM)

Throughout the acquisition process, a formal record of evolving system requirements is contained in the Operational Requirements Document (ORD). Within the Air Force, these requirements are also summarized in the RCM. Developed during concept exploration and refined during subsequent phases of the acquisition process, the ORD and it's accompanying RCM formally state the performance and related operational

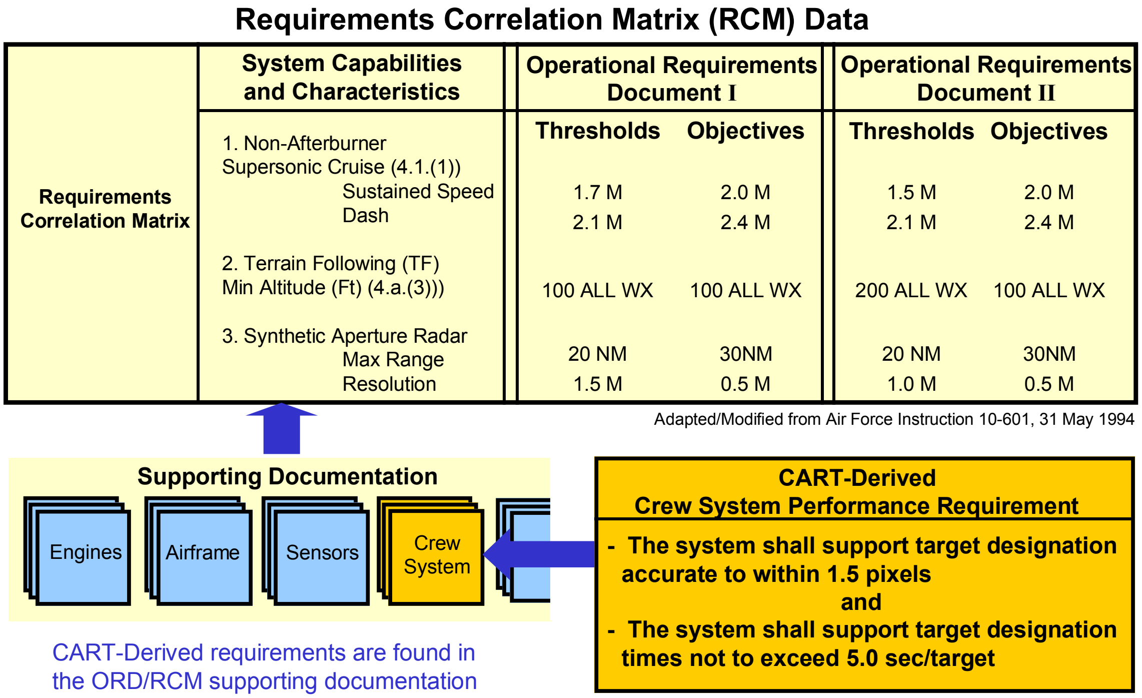

Figure 5. CART's role in supporting the requirements-specification process.

parameters for the proposed system. Shown in Figure 5 are components of an RCM for a hypothetical strike fighter aircraft. Requirements are stated in terms of *operational* capabilities and characteristics that the aircraft must exhibit. Notice that for each stated capability or characteristic, there are both "threshold" and "objective" values listed. A *threshold value* reflects the minimum acceptable operational performance for the proposed system. The *objective value*, however, represents a higher degree of capability that would lead to an identifiable increase in operational performance. In this example the threshold value for sustained, non-afterburner flight is Mach 1.7, whereas the objective value is Mach 2.0. Since the ORD and RCM are living documents that evolve over time, they also include the ongoing revisions to the requirements. Notice that ORD II data represent a change in requirements from ORD I. The threshold value for sustained non-afterburner flight has been revised downward to Mach 1.5. Supporting rationale for both the initial requirement and subsequent changes to the requirement are documented. These justifications and rationale are often based on the results of a specific tradeoff analysis or trade study examining the relative impacts of various levels of a given parameter on mission outcomes.

Documentation of CART-derived requirements

The goal of the crewstation performance requirements generated using CART is to provide a performance benchmark against which crewstation designs can be evaluated. For example, a simulation-based trade study examining alternative air-to-ground radar systems for the strike fighter might conclude that a key determinant of mission success is the operator's ability to quickly and accurately designate a target aimpoint on the radar image. Examining target-designation task performance and tracing this performance to mission outcomes, CART data analysts could identify specific levels of designation-performance that the crewstation must support in order to achieve the desired mission outcomes. In the example of Figure 5, it is determined that cursor designation must be achieved within 1.5 pixels of the desired aimpoint and take 5 seconds or less.

It is not anticipated that CART-generated requirements such as these will be stated explicitly at the level of the

ORD and RCM. Rather, they will be passed to the system designers with the lower-level trade study documentation that supports the ORD and RCM. By providing these performance-based crewstation requirements relatively early in the acquisition process, the CART approach promises to result in the faster, less-costly acquisition of more effective manned systems.

Discussion and Conclusion

As M&S technologies continue to make rapid advancements, their utility and value to the acquisition process continue to increase. However, there is still room for improvement in both the tools and processes being implemented to support acquisition. It is generally accepted that -- in order to reap the full benefits of M&S -- we need to develop increasingly valid simulation environments and to better share these environments and data within and among acquisition communities.

Representing the current framework for M&S in acquisition, the Simulation Based Acquisition (SBA) vision identifies three goals for enhancing the acquisition process:

- reduce the time, cost, and risk associated with acquisition,
- increase the quality of the resulting systems,
- enable integrated product and process development.[4]

The DOD M&S Master Plan identifies *six specific objectives* that will help achieve these goals:

1. develop a common technical framework for M&S,
2. provide timely and authoritative representations of the natural environment,
3. provide authoritative representations of systems,
4. provide authoritative representations of human behavior,
5. establish an M&S infrastructure to meet developer and end user needs,
6. share the benefits of M&S.[5]

CART will help realize Objective 4 of the DOD M&S Master Plan by providing the capability to readily integrate models of human performance into the constructive modeling activities that address overall system performance. CART-developed methods and tools will be used to integrate human-performance representations into early constructive simulation activities and to help generate human / system performance requirements that a proposed system must support. These requirements will then help focus crewstation design activities, enable early identification of potential crewstation design problems, and provide performance-based standards against which crewstation designs can be tested. By incorporating a representation of the human operator and demonstrating the operator's impact on mission performance, a better representation of the total system will be provided and judicious acquisition decisions regarding total system requirements can better be made. In so doing, CART implementation will support the SBA objectives of reducing acquisition time, cost, and risk while increasing system quality and effectiveness.

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